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A Strategic Science and Technology Planning and Development Process Model

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ABSTRACT

This paper contributes to the understanding of generalized strategic science and technology (S&T) planning and development through application of a developed process model to the research and technology initiatives of the U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC). A reflective case study is used to document how the organization refocused and formalized its previous method of S&T planning and development to more relevantly and responsively support: (a) the present war on terrorism, (b) the need for near-term solutions to deployed military system capability gaps, and (c) maintenance of a future perspective and technology development competency. For model creation, a middle management steering group and action teams were formed (under change management sponsorship of a champion) to formulate and implement an improved process model considered essential to near- and longer-term organizational success and the ever-present goal of providing superior technology for a superior Army. A technology manager can use elements of this paper and its described approach and methodology, derived strategic S&T planning and development model, and identified implications (challenges, lessons learned, and success measures and evaluation criteria) to more effectively and efficiently review, assess, and revise as needed the S&T initiatives of other organizations.

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INTRODUCTION

One of the many challenges of a science and technology (S&T) development organization is how best to focus and manage its mission, vision, goals, objectives, and customer/stakeholder needs within the constraints of budgets, human and physical resources, and schedule requirements. The need for continuous performance improvement is critical to technical organizations in an era of dynamic changes, economic constraints, and international competition. To these ends, organizations must focus on specific S&T portfolio planning and development to ensure that desired and timely results are achieved, and that customers needs and requirements are satisfied within available constraints. The primary questions this paper addressed are: (a) what are the elements of an overall philosophy and process to guide systematic S&T planning and development by organizations and technology managers? and (b) how can S&T management and development activities such as: customer/stakeholder needs/requirement definition and understanding, system-of-systems engineering, systems engineering, technology scanning, and S&T plan development be integrated into a systematic organizational approach and model?

This paper focuses on the entire strategic S&T management system and planning and development process from customer/stakeholder needs and requirements identification and funding allocations, to enterprise-wide product development results. Required for full S&T development implementation is recursive S&T planning developed initially and revised as needed. Central to the process is the identification of all linkages, strategic functions, activities, roles, responsibilities, and deliverables. Essential for continuity are formalized S&T plans complete with roadmaps that visually portray why specific efforts are initiated, and what, when, where, how, and who will be responsible for customer/stakeholder needs and requirements satisfaction within identified funding/budget limits and developed schedules.

The objective of this paper is to provide a better understanding of generalized strategic S&T planning and development, with specific application of the developed process model to the research and technology development initiatives of a focus organization--the U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC) of Warren, Michigan. A reflective case study is used to document how TARDEC refocused and formalized its previous method of S&T planning and development to more relevantly and responsively support: (a) the present war on terrorism, (b) the need for near-term solutions to deployed military system capability gaps, and (c) maintenance of a future perspective and technology development competency.

Outlined and described in the remainder of the paper are: (a) the research approach and methodology used, (b) a reflective case description of the target organization, (c) results achieved, (d) implications for managers of technology including challenges, lessons learned, and

success measures and evaluation criteria, and (e) a summary and conclusion. A technology manager should be able to use elements of this paper to review, assess, and revise, as needed the S&T initiatives of other organizations.

RESEARCH APPROACH AND METHODOLOGY

Research Foundation

To answer the primary questions of the paper, a review of relevant literature was initially undertaken. Primary areas of concentration were: (a) strategic planning, (b) systems theory, (c) management of technology, (d) engineering and project management, and (e) technology transfer. Secondary areas of search were: (a) S&T planning and development methods and paradigms, (b) issues of dynamic near and future customer needs and requirements definition, (c) system-of-systems engineering, and (e) systems engineering. From these reviews, a variety of organizational and technology management challenges and required thrusts were identified.

Organizational Challenges and Thrusts

Technology organizations continue to face the challenges of ensuring that S&T efforts produce value to society, the economy, and their organizations (Geisler, 2001). To respond to the value challenges, organizations need to initiate two thrusts. The first is to ensure that research and development (R&D) activities are fully integrated and that full collaboration exists within the organization and with external stakeholders. In explaining the evolution of the R&D function, Miller and Morris (1999) point out that a key element is the inclusion of a full range of stakeholders in the R&D process. These stakeholders include partners, customers, R&D, marketing, and production representatives. Their participation supports the development of a shared context (i.e., needs and values) for knowledge leading to the technology, the developed technology, and resultant products. For example, technology pull (from users) and push (from developers) satisfy both needs and values, and contribute to a shared context for all stakeholders. Chiesa (2001) further highlights the need for R&D activities to be fully integrated with competitors, suppliers, customers, and distributors. This first thrust forces the organization to take on a second thrust.

The second thrust is to develop and execute an integrated management approach for multiple layers of strategies and best practices for R&D and portfolio management. The latter being the balance of projects and activities that best support the mission, vision, goals, and objectives of the organization and the needs of its stakeholders. Matheson and Matheson (1998) define the need and a series of best practices to connect a multitude of corporate, business, portfolio, and project strategies. According to these researchers, technology strategy best practices include: (a) coordinating long-range business and R&D plans, (b) developing a global technology plan that

focus on end customer needs, and (c) designing a progression of technology. Portfolio management best practices include: (a) evaluating the R&D portfolio, (b) balancing innovations and incremental improvements, (c) managing the pipeline (supply chain), (d) balancing across strategic objectives, and (e) managing and prioritizing different R&D efforts. Project strategy best practices include: (a) the need to fully resource projects, (b) evaluating projects quantitatively, (b) focusing on factors that create value, (c) evaluating and planning all projects, and (d) agreeing on measurable goals. The extent and scope of these best practices point to the need for a systematic approach to organizational technology management.

Technology Manager Challenges and Thrusts

In the past, managers have used various organizational management tools to improve performance (Rigby, 2001). Today, S&T-focused organizations and technology managers are turning to an expanded and integrated set of initiatives such as strategic management, portfolio management, technology roadmapping, project management, and knowledge management to address the challenges they face. Technology managers are now finding that they must manage and function in an R&D environment pursuing two thrusts: (a) integrating core processes throughout the organization, and (b) implementing multiple strategy layers and best practices. These thrusts create challenges for technology managers that include: (a) strategic planning for technology products, (b) new product project selection, (c) organizational learning about technology, and (d) technology core competencies (Scott, 1998).

Evolving technology organizations and their managers are achieving positive performance outcomes by using an approach of integrating core processes throughout multiple levels in the organization. Core processes include:

- **Strategic management**: the process by which the organization provides an integrated management system and enables the organization to achieve its vision, mission, goals, and objectives.
- **Program/portfolio management**: the process by which the organization provides an integrated set of technologies and projects to meet the organizations strategic direction.
- **System-of-systems engineering/systems engineering:** the process by which customer needs are converted into detailed requirements and specifications.
- **Project management:** the process by which projects are planned, organized, directed, and controlled.
- **Technical:** the process by which the organization produces the products (e.g., software development).
- **Learning/knowledge management:** the process by which the organization improves its capabilities.

These core processes use various methods and tools to develop and manage a project portfolio. Steps in the portfolio management process include: (a) identifying the R&D budget, (b) defining potential R&D projects, (c) evaluating projects, (d) selecting projects, (e) implementing projects, and (f) measuring and adjusting projects and the portfolio (Chiesa, 2001).

Case Study Method and Focus

To better understand how organizations and technology managers can successfully implement the above core processes and manage challenges and thrusts, a reflective case study focusing on a target technology development organization was initiated. The essence of a reflective case study methodology and approach, as described by Kotnour and Landaeta (2004), consists of: (a) abstracting experience gained, (b) identifying approaches, processes, tools, challenges, and (c) developing lessons learned from a project experience for the benefit of a broader audience of program, technology, and engineering managers. Other researchers contend that both successful and unsuccessful project experiences offer unique perspectives for learning (Argyris and Schon, 1978; Follet, 1927, and Hill *et al.*, 1999). Therefore, the writer's challenge is to observe, document, and provide engineering managers with the needed knowledge to address organizational problems and needs (Kanter *et al.*, 1992; Kleiner and Roth, 1997; and Kotter 1996). While the case study method and focus of the research reported in this paper is on a single target organization, it is hoped that others will find the ideas and developed process applicable to other organizations and the challenges they face.

The experience gained by the authors in the creation and implementation of an S&T planning and development process model offered a unique opportunity to align a technology management organization's challenge with a performance improvement development and implementation approach, and to share this experience with others. Findings and conclusions presented in this reflective case study are based on a one-year and continuing development and implementation effort by the authors. The ultimate organizational objectives of this endeavor were to develop, implement, and document a strategic S&T planning and development process model that could be used to satisfy technology developer and customer/stakeholder S&T goals and objectives for the target organization and perhaps serve as an example for others.

Diverse discipline areas included in an initial literature review were: strategic planning, systems theory, management of technology, and engineering and project management. Important information gleaned during this theory and practice review were model parameters, and the identification of applications and lessons learned from the experience of other organizations. In addition to a literature review, interviews were conducted with organizational technologists, directors, and others with a vested interest in the target organization's S&T process. Following these preliminary steps, a steering group was formed and offsite meetings held to further discuss the state of the present system for S&T planning and development. Action teams were formed to

delve further into problems and solutions. Insights gained during these meetings resulted in the development of a basic concept model that included various parameters and interrelationships important to technology managers and developers. Literature search, interview results, and case study information were then analyzed and integrated to determine if a developed process model framework and its parameters and interrelations could be supported or refuted. From these process development activities, the model was applied, results obtained, and advantages over earlier methods noted. A background and specifics of the studied organization are discussed in more detail in the following section.

CASE DESCRIPTION

Focus Organization Overview

The U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC) is the nation's laboratory for advanced military ground combat and support vehicle technologies. Its parent organization is the Army's Research, Development and Engineering Command (RDECOM). Because TARDEC is headquartered in Warren, MI (a part of metropolitan Detroit and the world's automotive capital), the organization is uniquely positioned to ensure that it remains committed to developing and delivering near- and longer- term advanced military technologies. The organization accomplishes its mission and vision through research, development, and engineering, leveraging and integrating advanced technology into ground systems and tactical (support) equipment throughout a system's life cycle. The organization is committed to increasing the Army's agility, versatility, responsiveness, deployability, lethality, sustainability, and survivability, thus providing advanced ground vehicle and support system technologies for a superior Army. [*TARDEC Information Booklet* (2004)]

Traditionally, TARDEC has focused on program execution and S&T planning and development for the next generation of programs--primarily with a longer-term (3-years and beyond) horizon. The organization's mission is to research, develop, engineer, leverage, and integrate advanced technology into Army ground systems and support equipment throughout the life cycle. TARDEC's 1,100 associates develop and maintain vehicles for all U.S. Armed Forces, many federal agencies, and more that 60 foreign countries. S&T advances in collaboration with the Army's combat developer and customer soldiers, ensure that robust equipment is developed and fielded that meets aggressive cost, schedule, and performance standards. TARDEC functions to stimulate technology transfer, and to build solid relationships with industry and academia to develop dual-use technologies. To this end, TARDEC's technology transfer arm, the National Automotive Center (NAC) is charged with actively collaborating with private industry to leverage commercial automotive technologies for military use. [*TARDEC Information Booklet* (2004)]

It is important to understand the scope and diversity of TARDEC's responsibilities and program activities to produce material solutions for Army needs. To accomplish its mission, TARDEC is charged with pushing state-of-the-art programs that include: (a) power and energy systems (including hybrid-electric and fuel cells), (b) advanced collaborative environments, (c) unmanned vehicle developments and robots, (d) analytical/physical/embedded simulations, and (e) survivability systems. An example of the later was the development of add-on-armor kits for High Mobility Multipurpose Wheeled Vehicles (HMMWVs) currently deployed in Iraq to protect occupants against ballistic and explosive threats. These survivability kits were developed and deployed in a period of months instead of a more customary and lengthy period. In addition, and as an indication of the diversity of its activities, TARDEC's tactical support activities include development programs for: next generation software, water generation and purification, petroleum (fuel and lubricant) research, military bridging, countermine equipment, logistics equipment, fuel storage and distribution, and quality surveillance equipment.

To sustain its mission, roles, and responsibilities, TARDEC recently developed and implemented an improved strategic S&T program management system to ensure that the organization remains relevant and responsive to its customers--now and in the future. This system revision was initiated because of the organization's responsibility to continually improve its performance during the present war on terrorism, and its ongoing mandate to provide superior technology for a superior Army in the long term.

Interfaces and Responsibilities

As Figure 1 illustrates, TARDEC serves two masters with regard to providing S&T operational solutions and support services. They are: (a) the RDECOM that provides first-level approval and recommendations of S&T project initiatives such as Advanced Technology Objectives (ATOs), and (b) its primary customers--Program Executive Offices (PEOs) and Project Managers (PMs) who have general program (e.g., ground combat systems) and specific project (e.g., armored Stryker Brigade vehicles) needs and requirements. This later group represents (from a TARDEC perspective) the ultimate customer--soldiers and the organizations that develop their doctrine and tactics, provide training and logistics support, etc. As such TARDEC fits into and supports a Soldier and Ground Systems Life Cycle Enterprise--a life cycle system of Army commands, enterprises and alliances designed to function as a network of linked organizations that are integrated and function as an enterprise system of systems. While this is a summary chart, numerous other Army and Department of Defense (DoD) elements (including contractors) are involved in the complete S&T interface process model. For example, funding is authorized and provided by the U.S. Congress, through the Assistant Secretary of the Army for Acquisition, Logistics and Technology [ASA(ALT)], for TARDEC S&T activities based on review recommendations at the RDECOM level. In some cases, contractor support is unique to an

organization like RDECOM, but some contractors support multiple elements as is the case with some of the contractors that support customers and TARDEC S&T as indicated below. While not complete, all essential elements are represented in Figure 1 for the purpose of this paper.

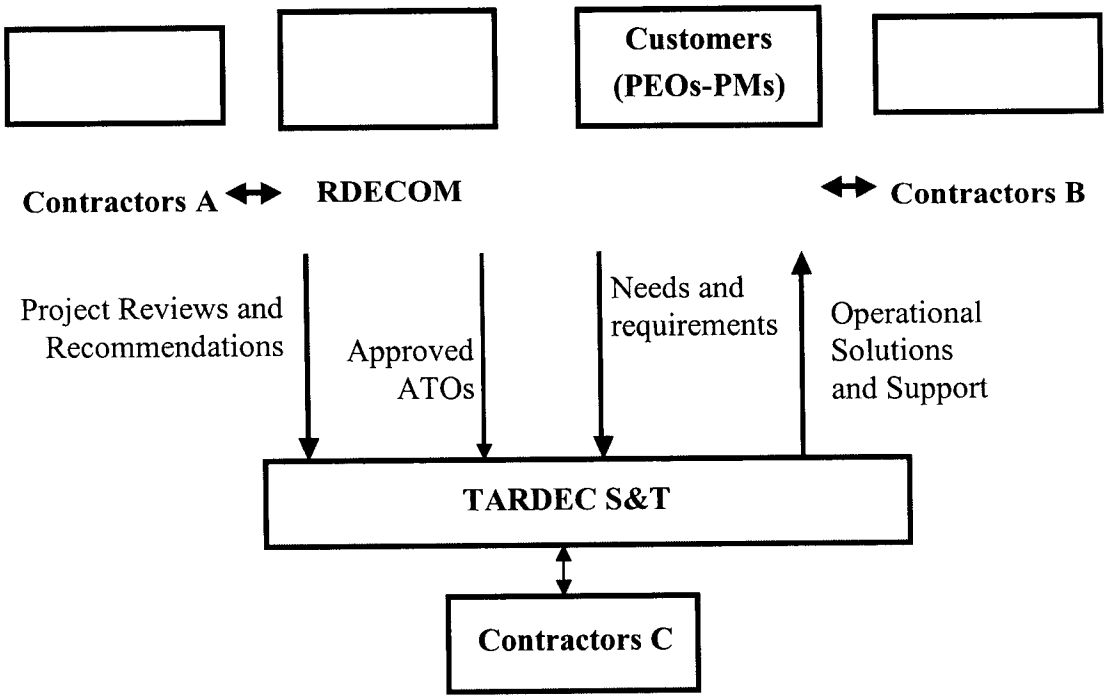

Figure 1. TARDEC S&T interface process model

Table 1 provides answers to the following TARDEC-S&T related process model questions: (a) what customer/stakeholder services are performed? and (b) what products and deliverables does the organization produce? While Table 1 is not all-inclusive for TARDEC, because engineering, some development, and operations business units are excluded, it does portray primary TARDEC research and technology development responsibilities. From the table it becomes evident that S&T elements are involved in numerous and diverse supporting services and activities. Central is its role in providing near- and longer-term S&T capability developments through technology creation, or adoption/adoption of commercial-off-the-shelf (COTS) systems. It is also important to recognize that TARDEC does not have production capabilities. Instead they provide S&T development and advisory services for other Army and DoD agencies that initiate, through major contractors and vendors, large-scale acquisition and production of operational combat and support systems.

Customer/Stakeholder Services	Products and Deliverables
1. Platform concept developments	• Concept identifications

2. Platform concept system-of-systems analyses	• Computer/virtual platform concept modeling and simulation
	• War gaming inputs and results
	• Concept simulation and tradeoff results
3. Research activities	• Research results and reports
4. Model developments	• Computer models and reports
	• Physical models and reports
5. Technology developments	• Created, adapted, and/or adopted technologies
6. System/subsystem/component testing and analyses	• Developed S&T testing and analysis reports
	• COTS S&T testing and analysis reports
7. Platform demonstrator/prototype developments	• Virtual models
	• Physical models
8. Platform demonstrator testing and analysis	• Virtual models results
	• Physical models results
9. Dual-use application identification	• Reports
	• Technology transfers
10. S&T planning	• S&T plans and roadmaps
11. Specification shaping	• Information to Program Managers
12. Funding identification	• Funding requirements

Table 1. TARDEC customer/stakeholders S&T services, products, and deliverables

The Need for Change

In spite of established and understood S&T interface process model relationships (ref. Figure 1) and accepted TARDEC customer/stakeholder services, products, and deliverable responsibilities (ref. Table 1), two organizational problems were generally recognized. The first was that there was a need to improve the way the organization interfaced and collaborated with those external to the organization--namely its PM customers, stakeholders, the active military, and funding groups. Second, it was felt that these interface relationships could be improved by formalizing the organization's internal method and processes for periodic S&T planning and development. The driving rationale for supporting these felt needs was to maintain and improve TARDEC's continued viability as a relevant, responsive, and ready organization to effectively and efficiently manage its external and internal relationships and activities. As a result of these identified improvement needs, it was decided that a concerted action be taken in early 2004 to address and resolve these problems and others that evolved.

Approach Details

In an effort to identify and solve existing organizational problems, a "grass-roots" approach, which balances middle management sponsorship and leadership with bottoms-up involvement, was taken to identify and implement several strategic "quick wins." This approach was an alternative to the more traditional strategic organization planning and renewal process flow (mission, vision, goals, objectives, etc.). To initiate the renewal process, a middle management steering group and champion were identified, and a series of offsite working sessions held at a nearby conference center beginning in mid-May 2004. These group sessions, and the open dialog that occurred under the leadership of an "outside" facilitator resulted in the identification of a number of organizational problems that participants felt existed. After grouping, six problem categories were identified. They were the need to: (a) reestablish a vehicle (platform) integration role, (b) change perceptions of the organization, (c) "build the bench" by enhancing the workforce, (d) develop a collaboration strategy, (d) formalize S&T planning, and (e) improve the strategic budgeting/funding process. Of the six problem areas, the latter three relate to the topic of this paper.

The next step in this "grass roots" process was to identify six performance improvement project teams and leaders. For several months, team meetings were held with weekly status reported. The purpose of these reviews was to: (a) identify a problem statement, (b) establish success criteria and objectives, (c) define problems, (d) develop solution concepts, (e) and develop implementation and resource plans. As part of these team efforts, primary upper-level sponsors were identified with support solicited. Concurrently, benchmark identification and analysis of other organizations were conducted, as was the development of an overall philosophy and S&T program management and solution suite.

Since the mission, goals, and objectives of the organization were understood and remained unchanged, a process flow was developed that identified a strategic S&T program management model, which was intended to represent the entire and revised TARDEC S&T planning and development concept and process. Important in this model was the idea of "spiral" technology development--moving from long-term to shorter-term applications-with cycling between the identification of customer/stakeholder capability gaps and solutions. This technology development concept also applies to iteratively moving from a capability gap to a solution, and so on. After approval by the management steering group and champion of preliminary results achieved by improvement teams, the next phase of activities was to convert this concept model, objectives, and features into the next level of TARDEC S&T planning and development activities--definitions, descriptions and process flows. For more information and details on driving change from the middle in high-tech organizations, and an approach and lessons learned from a military S&T development organization see Bochenek *et al.,* 2005b.

RESULTS ACHIEVED

The Strategic S&T Process Model

This paper focuses on the entire TARDEC strategic S&T program management model and its elements, which are illustrated in Figure 2. Indicated are six main functional activities indicated by numbers introduced to guide the reader through the process. The basic idea is that initial S&T planning has taken place in an earlier period (usually annually), and the process of S&T development has followed. Requirements are turned into technology capabilities, TARDEC system-of-systems engineering integration occurs, and functional organizations provide S&T systems engineering and technology scanning reviews throughout the process. Concurrent with these process steps and on a regular basis, S&T replanning occurs and the process starts again.

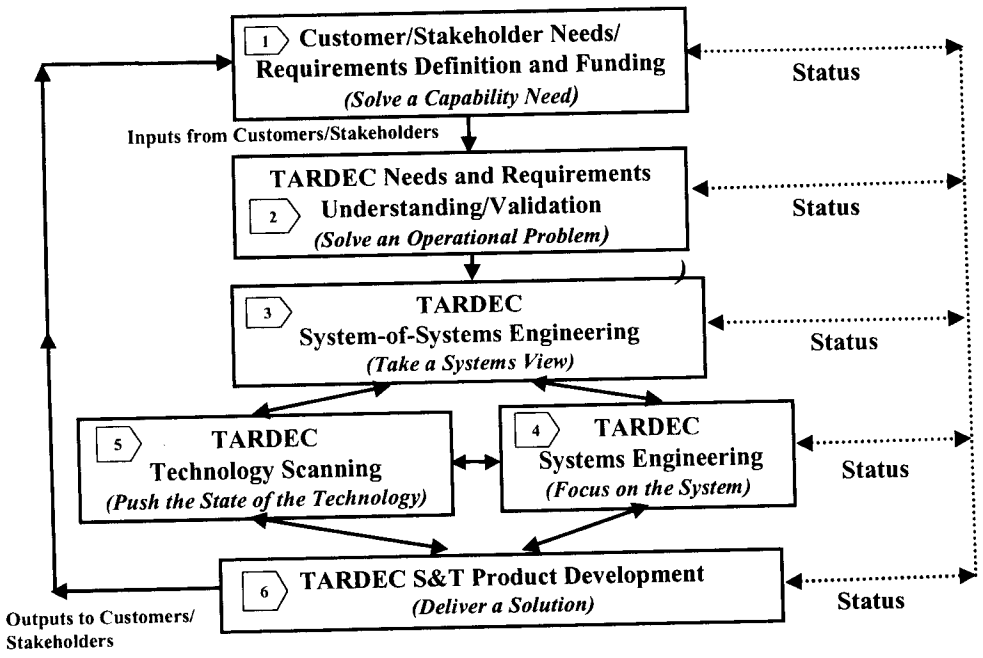

Figure 2. TARDEC S&T strategic program management model

This overall process follows the systems model that begins with inputs, in this case from customers and stakeholders, who seek solutions to capability needs and requirements. Following the identification and input of needs, requirements, and authorized funding, the process continues through various progressive steps. A systems view is needed by specialists who take a system-of-systems engineering look at the entire system under consideration. In the context of TARDEC and Army environments, an entire system or platform would be an armored vehicle such as a tank, or a tactical truck used to support combat operations.

The systems perspective included in this paper and implemented by TARDEC is consistent with the development and implementation of DoD policy initiated in early 2004 with regard to systems engineering. This policy was designed to: (a) revitalize and formalize the systems engineering process, (b) establish organizational responsibilities, (c) require that processes, resources, and metrics be established, (d) formalize reviews, and (e) that system engineering plans be developed (Wiltsie, 2004).

Following system-of-systems engineering, organizational systems engineering and partners become the focal point of development activities in this process. Their responsibility, based on their specialized skills, is to "focus on systems" and eventually to perform various analyses at the systems level. In the case of TARDEC and critical to its mission are: mobility systems (e.g., engines, transmissions, wheels or tracks, and hybrid components such as motors, switches, inverters, motor controllers and fuel cells), survivability systems (e.g., armor, active protection), intelligent systems (e.g., robotics, crew interfaces, simulation), maneuver sustainment, (e.g., fuels, propellants, lubricants, maintenance, water purification), and software development (e.g., command and control). Continued in the process is the need for TARDEC to push the state-of-the-art through: (a) technology scanning (to understand what technologies are available), and (b) through the development of technologies. An important result of this awareness is an understanding of where technology gaps exist that prevents accomplishment of customer needs and requirements.

Finally, the process that began during an earlier period is again iterated. For the organization to deliver a solution, S&T plan development must occur. S&T strategic planning, which is performed enterprise wide, results in an S&T plan and roadmaps that describe and visualize technology initiatives, responsibilities, and timelines. Throughout the process, status is provided to others including customers who have needs and requirements, and stakeholders who provide funding and program guidance.

Phased Process Flow Elements

The following is a more detailed discussion of the major elements of the S&T strategic management process. Included are considerations for: the function, activities performed, the responsible party or parties, supporting elements, and resultant deliverables.

Customer/Stakeholder Needs/Requirements Definition and Funding. The first phase of this developed system, illustrated in Figure 3, includes the various customer and stakeholder partners who are the focal point of and provide inputs to TARDEC's S&T strategic program management activities--their responsibilities being assessing a variety of needs and requirements, determining schedules and milestones, and establishing funding levels.

S&T Strategic Function	Activity Description	Primary Responsible Parties	Supporting Element(s)	Deliverables
1 **Customer/ Stakeholder Defined Needs, Requirements, and Funding**	• Identify operational needs and capability gaps • Identify needs and/or requirements • Identify need dates • Establish funding levels	• Customers/ stakeholders • Funding agencies	• TARDEC and other Centers and Commands	• Needs and requirements • Schedule/need dates • Funding levels **(Inputs to TARDEC)**

Figure 3. Customer/stakeholder activities and responsibilities

Figure 4 illustrates the second phase of S&T strategic activities associated with actions initiated by TARDEC to understand customer needs and requirements. Considered are operational needs and gaps in capabilities. Required for this analysis are inputs and meetings with customers, stakeholders, funding agencies, and internal elements of TARDEC. Results of this activity are listings of needs and requirements that have been verified by those who have needs and requirements. Having a verified, prioritized, and understood list of needs and requirements allows TARDEC to move forward to the next series of activities in this phase: developing schedules and beginning the process of identifying funding shortages.

S&T Strategic Function	Activity Description	Primary Responsible Parties	Supporting Element(s)	Deliverables
2 **TARDEC Needs, Requirements Understanding**	• Understand operational needs and capability gaps • Understand validated needs and/or requirements • Understand schedules and funding levels	• TARDEC responsible elements	• Customers/ stakeholders • Funding agencies • TARDEC supporting elements and potential partners	• Listing of needs and/or requirements • Schedule/need dates • Funding levels

Figure 4. TARDEC needs and requirements activities and responsibilities

System-of-Systems Engineering. The third phase of system activities, pictured in Figure 5, involves the recreation of a system-of-systems engineering function and team. Responsibilities of this team would include: (a) the initial review of needs and requirements submissions and translations to technical specifications/metrics, (b) surveying and assessing candidate technologies, (c) developing and performing analyses of system (platform) alternatives, (d) developing computer-based models and performing simulations, (e) identifying roles and responsibilities for those within TARDEC and partners, (f) parsing actions to internal and external groups, (g) tracking activities and accomplishments, and (h) reporting status. This team

works closely with existing technology teams in TARDEC's research, development, engineering, and the NAC business units. Understandably, this activity is critical to the success of the S&T

S&T Strategic Function	Activity Description	Primary Responsible Party	Supporting Element(s)	Deliverables
3 **TARDEC System-of-Systems Engineering**	• Understand needs/ requirements • Understand the state of platform technologies • Identify technology gaps • Develop technology capability maturity path • Develop platform concepts and models • Perform platform simulations and analysis of alternatives (trade and risk studies) • Identify roles, responsibilities, and partners • Parse actions • Integrate and track (internal and external) activities • Report status	• TARDEC System-of-Systems Engineering team	• TARDEC Business groups • Other organizational elements • Partners	• Integrated action plans • Trade studies • Technology gap and capability maturity path identification • Overall schedules and cost estimates • Identification of roles and responsibilities • Risk analyses • Analysis reports • Status reports • System-of-systems specifications • Geometric representations and performance predictions of platforms

development and planning process. There are numerous activities performed during this phase that include the development of system (platform) concepts, and performing system analyses and trade studies.

Figure 5. The TARDEC system-of-systems engineering function

Systems Engineering. The fourth phase of this system is illustrated in Figure 6. Various systems engineering teams, as appropriate, would perform: (a) systems analysis and integration, (b) computer model developments and simulations, (c) testing and demonstrations of prototypes, and (d) status reporting. An important activity performed by a variety of system elements (e.g., survivability, mobility, and intelligent systems) is defining system performance requirements. For example, would a proposed 400 hp engine fit into a system-of-systems allocated space envelope, and what are the tradeoffs? Other activities (in addition to those identified in Figure 6) would be the definition of system concepts and alternative weights, volumes, costs, and schedules. Another important aspect of systems engineering new technology deliverables is the "technology push" development of technologies and applications identified through the innovated efforts of organizational technologists. While these developments may not be needs or requirements driven, they may become significant contributions to customer organization--near term or in the future. Lines of communications must exist to make these new technologies or ideas known, with rewards and acknowledgement given to innovators.

S&T Strategic Function	Activity Description	Primary Responsible Parties	Supporting Element(s)	Deliverables
4 **TARDEC Systems Engineering**	• Understand needs/ requirements • Define system and performance requirements • Define system solution concepts and alternatives • Understand system-of-systems implications • Perform systems analysis, design, engineering, and integration • Understand the state of technologies • Identify technology gaps • Perform simulation and modeling • Develop demonstrators • Perform tests and demonstrations • Perform assessments of performance • Report status	• TARDEC functional groups (e.g., Mobility, Survivability, Intelligent Systems, etc.)	• Other TARDEC groups and elements • Partners	• Systems analyses • Prototypes • Test results • Reports • Schedules • Cost estimates • Systems specifications • New technologies

Figure 6. TARDEC systems engineering

Technology Scanning and Development. The fifth phase of the S&T Strategic Program Management System is pictured in Figure 7. This S&T strategic function involves technology scanning, performed by members of the system-of-systems and systems engineering teams. This activity involves an awareness and use of knowledge of the state-of-the-technology for ground vehicle combat and support platforms and systems. An important aspect of scanning and the identification of existing or near-time technology developments is the identification of existing technology gaps that prevent or delay the development of solutions for gaps identified in earlier phase activities.

S&T Strategic Function	Activity Description	Primary Responsible Parties	Supporting Element(s)	Deliverables
5 **TARDEC Technology Scanning and Development**	• Understand and use state of technology • Identify technology gaps	• TARDEC System-of-Systems Engineering Team • TARDEC Systems Engineering Teams	• Other TARDEC groups and elements • Partners • Other DoD groups • Industry • Academic institutions	• Reviews • Studies • Cost estimates • Reports • Risk analyses • Assessments of technology readiness levels (TRLs) • Acquired knowledge
6 **TARDEC S&T Plan Development**	• Develop, coordinate, and distribute S&T planning products • Report status • Communicate new technology developments	• TARDEC S&T Planning Team	• TARDEC System-of Systems Engineering Team • TARDEC Systems Engineering Teams • Other partners	• TARDEC S&T Plan • STOs • ATDs • Developed Technology **(Outputs to customers/ Stakeholders)**

Figure 7. TARDEC technology scanning and product development

Figure 8 illustrates the evolution of technology scanning and developed ideas and concepts. Initially, technology ideas are collected from a variety of sources (e.g., academic, industry, military, etc.), and organized in a database. Then TARDEC system-of-systems and system engineers, working in conjunction with PM customers during collaborative brainstorming evaluations, perform technology opportunity reviews using collected technologies from the database matched against identified and anticipated system needs. Results of these reviews are then included in a refined technology database for application as appropriate for current system modification or future system incorporation.

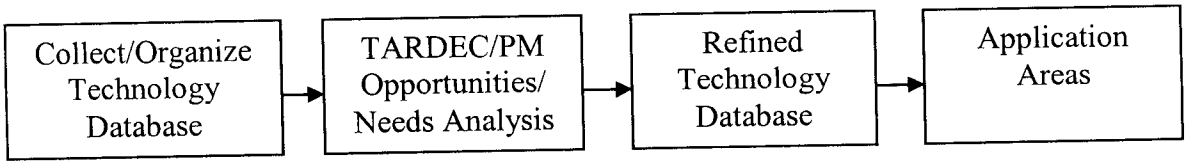

Figure 8. Technology scanning, collection, and application

S&T Product Development. The sixth and last phase of this process also portrayed in Figure 7 is S&T plan development. In reality there are multiple important results that occur during this phase of the S&T strategic planning and development process. The first consists of important outputs in the form of S&T plans developed by the TARDEC S&T planning team responsible for facilitating, coordinating, reporting status, and distributing developed S&T plans. These plans are the basis for TARDEC Advanced Technology Objectives (ATOs), Advanced Technology Demonstrations (ATDs), other technology development activities, and the identification of unfunded capability and technology needs. In addition, resultant S&T plans and activities that go into its development serve as the basis for overall budget and future budget submissions.

S&T plan development (i.e. deliver solutions) consists of defining: (a) technology R&D maturity paths and decision points, (b) transition plans, (c) funding and partnering requirements, and (d) risks. This planning is an evolving and continuous process that results in the development of a family of roadmaps that visually portrays paths from identified customer needs and requirements to development and implement plans and schedules. These roadmaps identify technology development issues of what, why, when (with milestones), how, and who (including partners) will participate in the process and their responsibilities. S&T plan development activities of TARDEC S&T strategic program management are described in more detail in Bochenek *et al.* (2005a).

The second result, and the ultimate output of this phase of activities, are the developments and transfer of technologies needed to satisfy operational gaps identified in the initial phase of the strategic S&T planning and development process--Customer/Stakeholder Needs/Requirements

Definition and Funding. TARDEC does not have a production capability as mentioned earlier, but instead is a service organization. As a result, a diverse set of service products and deliverables (previously identified in Table 1) are created for customers/stakeholders. In addition to S&T plans and roadmaps, included are: (a) concept identifications, (b) various analytical models and simulations, (c) physical models and prototypes, (d) testing, analysis, and feasibility reports, (e) technology transfers, (f) and project development proposals (e.g., ATOs) and funding needs. For more specifics on TARDEC products and deliverables refer to Table 1.

Preliminary Evaluation

Prior to the creation and implementation of an S&T planning and development process model, some customers and stakeholders criticized organizational planners and developers for not being as effective and efficient as they could have been. At issue were organizational relevancy and responsiveness. Only portions of a formal S&T planning and development system existed and documentation was limited. Further, a system-of-systems function has been eliminated years earlier. As a result of these shortcomings, key people in TARDEC realized that organizational S&T strategic program management improvements were needed.

Post implementation of the TARDEC S&T strategic program management model and process is yet to be fully evaluated. However, it has been determined that organizational learning has occurred and many (including key individuals) in the organization are now knowledgeable about the model and have supported its adoption. A first complete iteration through the process has been undertaken, and more complete results will be provided at a later date as full model and process implementation are achieved. It is important to note that top organizational management has recognized the importance of an integrated systems model and approach to S&T planning and development, and have made it their initiative. While results are preliminary, several implications for technology managers have been identified and include S&T planning and development challenges, lessons learned, and success measures and evaluation criteria. These initial results are included in the following paper section.

IMPLICATIONS FOR MANAGERS OF TECHNOLOGY

Challenges

Key organizational questions to be asked and answered by any organization and its technology managers is: why, when, and how should a strategic S&T planning and development management program be implemented? To answer these questions, the following sub-questions and resultant challenges must be asked and answered:

- Why is a change to an existing system or method of strategic S&T planning and development needed?
- Is there an acceptance that a change or a new method is needed?
- What is the best way to build consensus on a development approach or revision?
- Will the new process justify the time and energy that will be required for its development and implementation?
- Does needed management support exist to make this change a reality?
- What will be required to build the required infrastructure--people/skills/values and tools?
- Do the skills exist to build the processes and defining roles/responsibilities for the new approach?
- How will performance of the new system be measured?
- What are the hidden costs and risks of such an implementation?
- Will the organization support a systems-of-systems engineering function?
- Will higher-level leaders and organizational representatives, customers, stakeholders, partners, contractors, etc. accept the desired and resultant changes to S&T strategic program management?
- Will the timeframe for implementation support customer/stakeholder and organizational needs?
- Will real cost savings/avoidance be realized?
- Will this change make the organization more proactive and a leader in strategic S&T planning and development?

Of course, the corollary question to the above key question is: can an S&T organization that provides critical services, products, and deliverables to customers and stakeholders afford *not* to develop a formalized S&T planning and development management process in a world of constrained resources, expanding competition, and dynamic changes? The obvious answer should be *no*--assuming that there are shortcomings in an existing system that do not support the mission, vision, goals, and objectives of involved and affected organizations.

Lessons Learned

The following is a preliminary listing of lessons learned from the TARDEC S&T planning and development initiative to date. They are offered to help guide others who find value in this strategic S&T approach and process. Captured lessons learned are as follows:

- Be proactive as an organization to add significant value to S&T planning and development.
- Make customers/stakeholders part of S&T Strategic Program Management activities.

- Function as a team to improve relevancy and responsiveness to customer/stakeholder needs and requirements and funding agency accountability.
- Initially think top level downward from needs/requirements to system-of-systems to supporting systems, and upward for solution accomplishment and platform integration.
- Work to build win-win, collaborative partnerships (internal and external) and contractor relationships.
- View all activities as projects with performance, schedule, and cost measures.
- Function more in a systems mode.
- Take advantage of the synergy of Integrated Product/Project Teams (IPTs) both internally and externally for all major needs, requirements, and funded activities.
- Identify points of contact and responsibilities at all levels of S&T activities.
- Provide status (feedback) at each stage of S&T activities.
- One organization must serve to orchestrate the total process to ensure that all phases of the model are integrated, continuous, and complete.

Success Measures and Evaluation Criteria

During and subsequent to implementation of TARDEC's new S&T strategic program management system and process model, several implications for technology in the form of questions that can serve as success measures and evaluation criteria. Likewise, they function as a set of implications for other application change agents to think about and evaluate as they proceed down the S&T planning and development process modeling path for their own target organizational application. They include:

- In the end will this process result in the satisfaction of customer/stakeholder needs and requirements?
- Do process results improve or make the organization relevant and responsiveness to customers/stakeholders?
- Does the process significantly improve the organizations S&T planning, internal communications, and team building activities?
- Does the process directly support customer/stakeholder and S&T developer organizational missions, visions, goals, and objectives?
- Will the process encourage, build, support, and sustain collaborative synergistic partnerships (internally and externally) and encourage future relationships?
- Does the process support "market pull" customer needs and "technology push" (i.e. support for new technologies and applications identified by lower-level technologists)?

SUMMARY AND CONCLUSION

Summary

This paper identified the ongoing need for an S&T development organization to focus and manage its mission, vision, goals, objectives, and customer/stakeholder needs within the constraints of human and physical resources, budgets, and schedules to produce value to society, the economy, and their own organizations. Also recognized was the need for continuous performance improvement that is critical to technical organizations in an era of dynamic changes, economic constraints, and international competition. A literature search identified the need for technology driven organizations to respond to value challenges by focusing on internal and external R&D collaboration and integration, and to develop a formalized approach to manage multiple layer of strategies and best practices.

Also identified was the need for S&T organizations and technology managers to improve performance by using an expanded and integrated set of initiatives such as strategic management, portfolio management, technology roadmapping, project management and engineering, and knowledge management to address the challenges they face. Technology managers must now manage and operate in an R&D environment pursuing two thrusts: (a) integrating core processes throughout the organization, and (b) implementing multiple strategy layers and best practices. A set of core processes important to achieve positive performance outcomes were identified that ranged from strategic management to learning/knowledge management. Identified best practices for technology strategy, portfolio management, and project strategy point to the need for a systematic approach to technology management.

The target organization and resultant reflective case study was the U.S. Army's primary organization responsible for tank and automotive research, development, and engineering with a focus placed on its S&T planning and development activities. This organization was selected because the paper's authors were intimately involved in the development and implementation of a strategic S&T management system concept and process model. The objective of this effort was to enhance TARDEC and its collaborative partner's ability to: (a) respond proactively as an organization to add significant value through advanced ground vehicle and support system technologies, (b) function as a team to improve its relevancy and responsiveness, (c) view all activities as projects with performance, schedule, and cost measure accountability, (d) take advantage of internal and external synergism opportunities to effectively and efficiently manage all S&T activities, (e) establish points of contact and responsibilities at all levels, and (f) develop and maintain win-win collaborative partnerships.

For S&T strategic program model creation, a middle management steering group and action teams were formed (under change management sponsorship of a champion) to formulate and implement an improved process model considered essential to near- and longer-term organizational success and the ever-present goal of providing superior technology for a superior Army. In reality this model was an expansion of the classical systems model that includes inputs (i.e. needs and requirements from customers and stakeholders), the processor (i.e. TARDEC technology investigations and development), outputs (i.e. S&T plan development and deliverables), and feedback (i.e. progress status) throughout all phases of the process model. In addition to an S&T strategic program model, developed were an organization interface process model showing roles and responsibilities for critical internal and external entities, and identification of TARDEC S&T services (products and deliverables). Elements of a six-phase S&T strategic program model were decomposed by function to indicate activities, primary and supporting responsibilities, and deliverables.

Finally, a series of implications for managers of technology were identified that included challenges, lessons learned, and some success measures and evaluation criteria. These implications were derived from the process of developing the S&T strategic program model and its implementation.

Conclusion

The primary research questions this paper addressed were: (a) what are the elements of an overall philosophy and process to guide systematic S&T planning and development by organizations and technology managers? and (b) how can S&T management and development activities such as: customer/stakeholder needs/requirement definition and understanding, system-of-systems engineering, system engineering, technology scanning, and S&T plan development be integrated into a systematic organizational approach and model? Discussion elements of this paper and the models developed offer answers to the research sub-question. An overall philosophy and process were identified and addressed, and the elements of an S&T strategic management model were identified and described.

While the focus of the research reported in this paper is on a single military S&T organization with a somewhat unique mission, numerous S&T organizations that also have the responsibility to develop and transfer technology to customers and stakeholders can benefit from the results of this paper. Other researchers and technology managers should be able to use elements of this paper and its described approach and methodology, derived strategic S&T planning and development model, and identified implications (challenges, lessons learned, and success measures and evaluation criteria) to more effectively and efficiently review, assess, and revise as needed the S&T initiatives of other organizations.

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